Secrets of dust evolution from numerical simulations of GMCs

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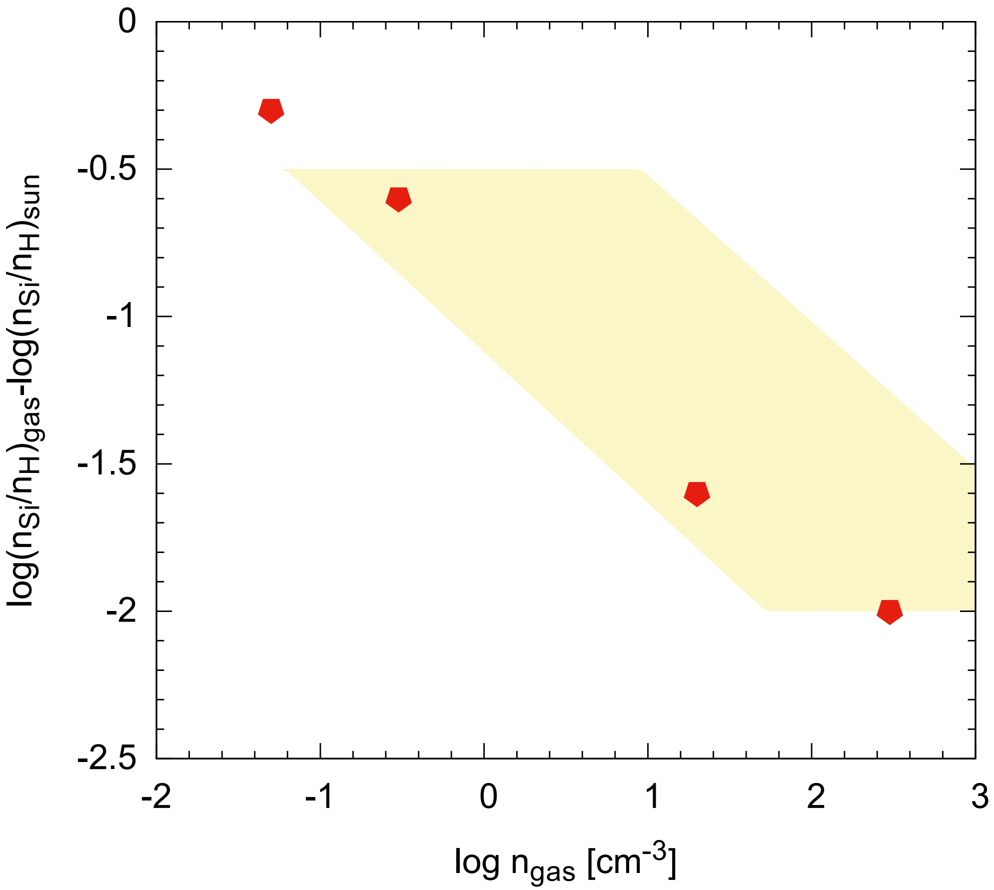
DFG Priority Program 1573

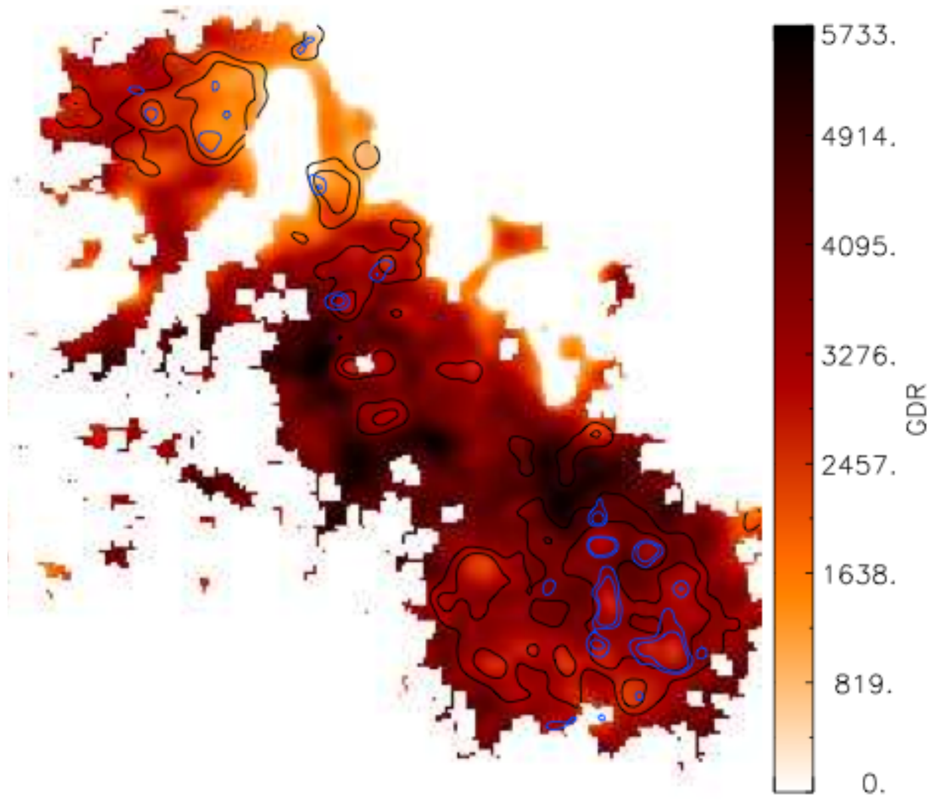
ISM-SPP

Interstellar Medium

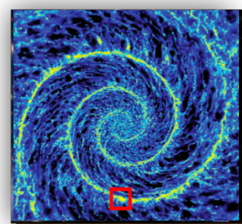
Small scale variations of dust properties



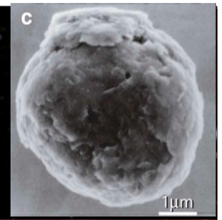
Si depletion – gas density relation in the local Milky Way from UV absorption lines

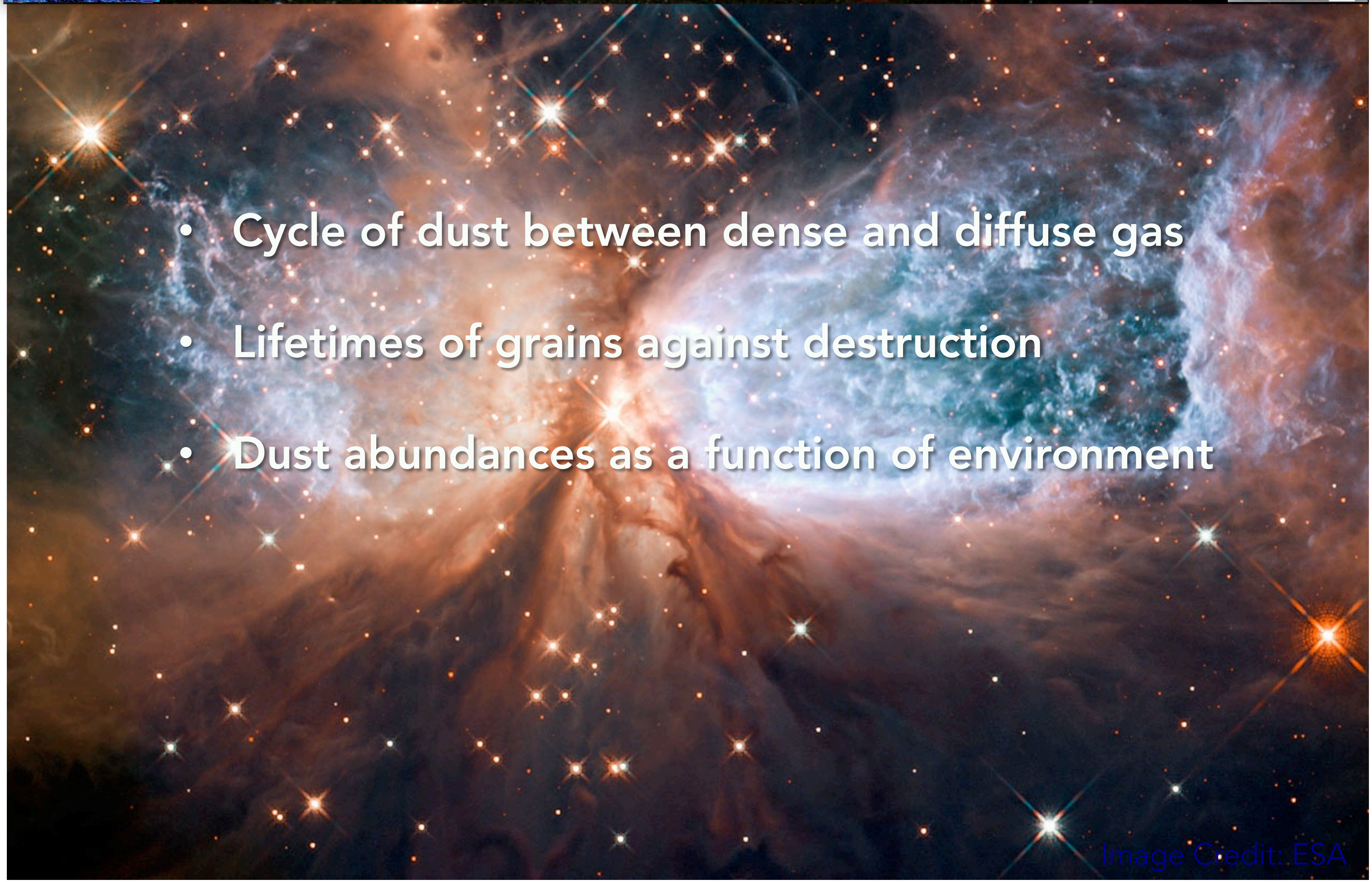


Herschel HERITAGE data with < 18 pc resolution in SMC in 5 bands (Roman-Duval, … Zhukovska'14)



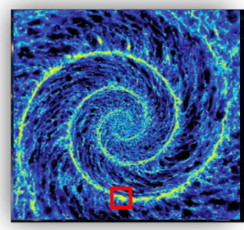
3D dust evolution model





- Cycle of dust between dense and diffuse gas
- Lifetimes of grains against destruction
- Dust abundances as a function of environment

Image Credit: ESA

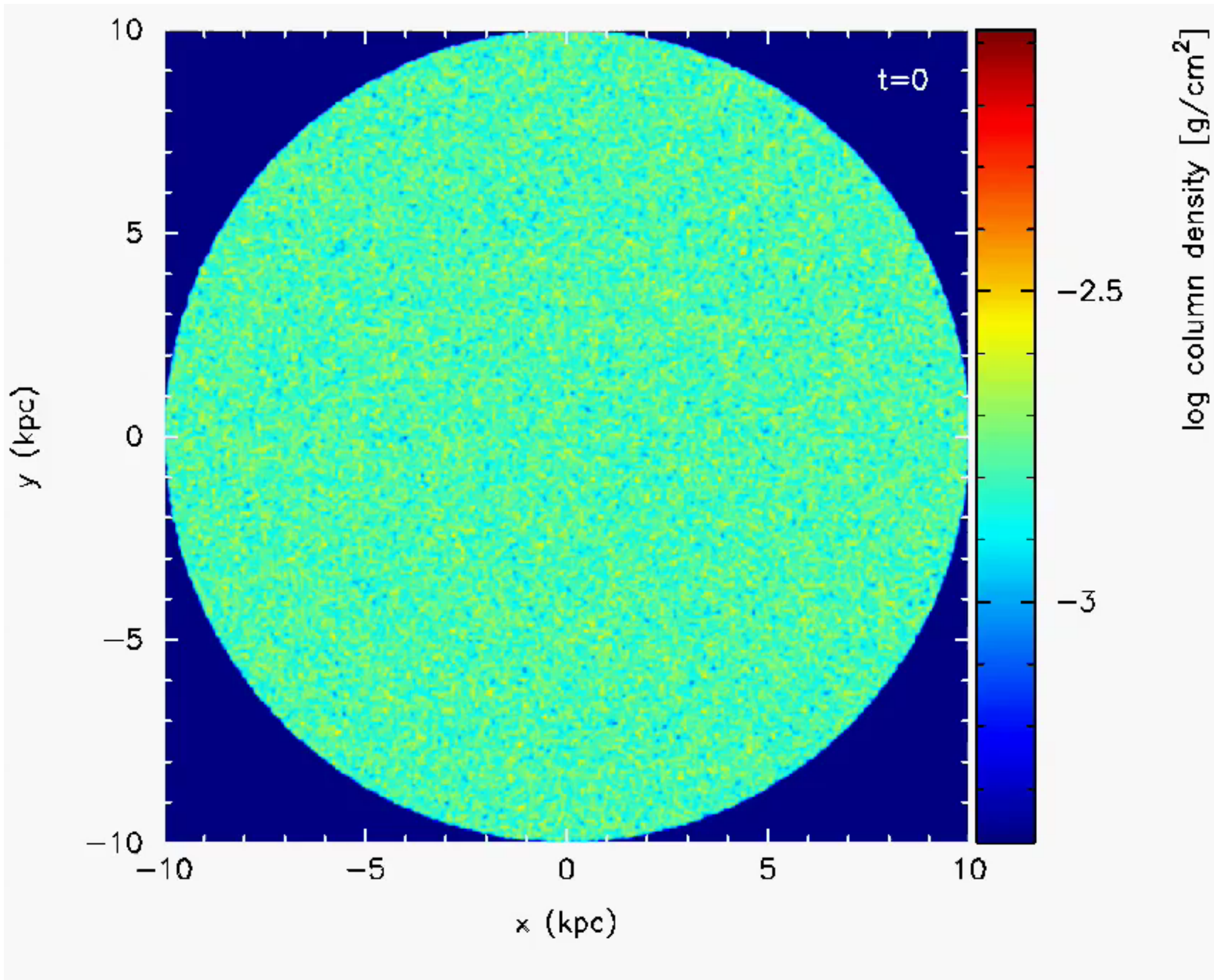


Numerical simulations of GMC evolution

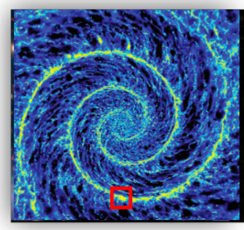
Evolution of spiral Milky Way-like disk

log column density [g/cm^2]

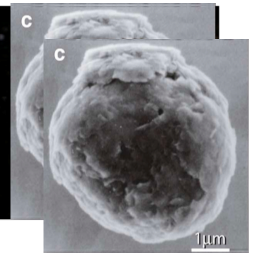
- Stellar gravitational potential with 2-4 armed spiral component
- Heating and cooling
- Self gravity
- Stellar feedback
    - instantaneous, inserted above a critical density
    - thermal+kinetic energy added as Sedov solution
- 8 million SPH particles
- Evolution time 300 Myr



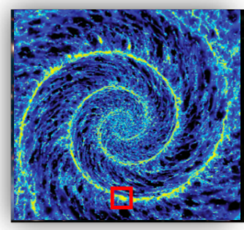
Dobbs&Pringle 2013



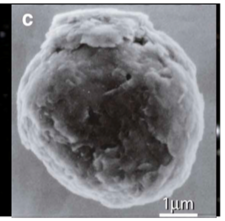
Dust evolution model



- Model dust evolution via post-processing of numerical simulations of GMC evolution
- Fix the total abundances, follow the fraction of key element in dust
- Start with abundances from diffuse ISM: 70% of Si in dust
- Include only main source and sink of dust
  1. Growth by accretion in ISM
  2. Destruction by SN blast waves



Dust model – growth in ISM



- Equation for condensation degree of element X Zhukovska+2008

$$\left(\frac{\mathrm{d}\,f_X}{\mathrm{d}\,t}\right)_{\mathrm{gr}} = \frac{1}{\tau_{\mathrm{gr}}} f_X(1 - f_X).$$

- Timescale of dust accretion

$$\tau_{gr}^{-1} \sim Z \frac{\alpha}{\langle a \rangle_3} \upsilon_{th} n_H$$

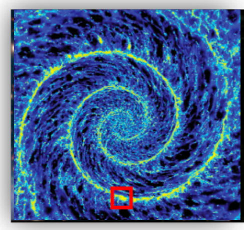
sticking coefficient

local conditions from SPH parts

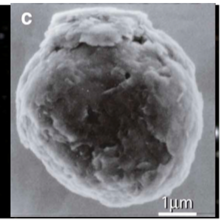
average grain radius

$$\langle a \rangle_3 = \frac{\langle a^3 \rangle}{\langle a^2 \rangle}$$

- Experimental work on dust growth at low T_{gas}: Krasnokutski+2014; Rouillé+2014



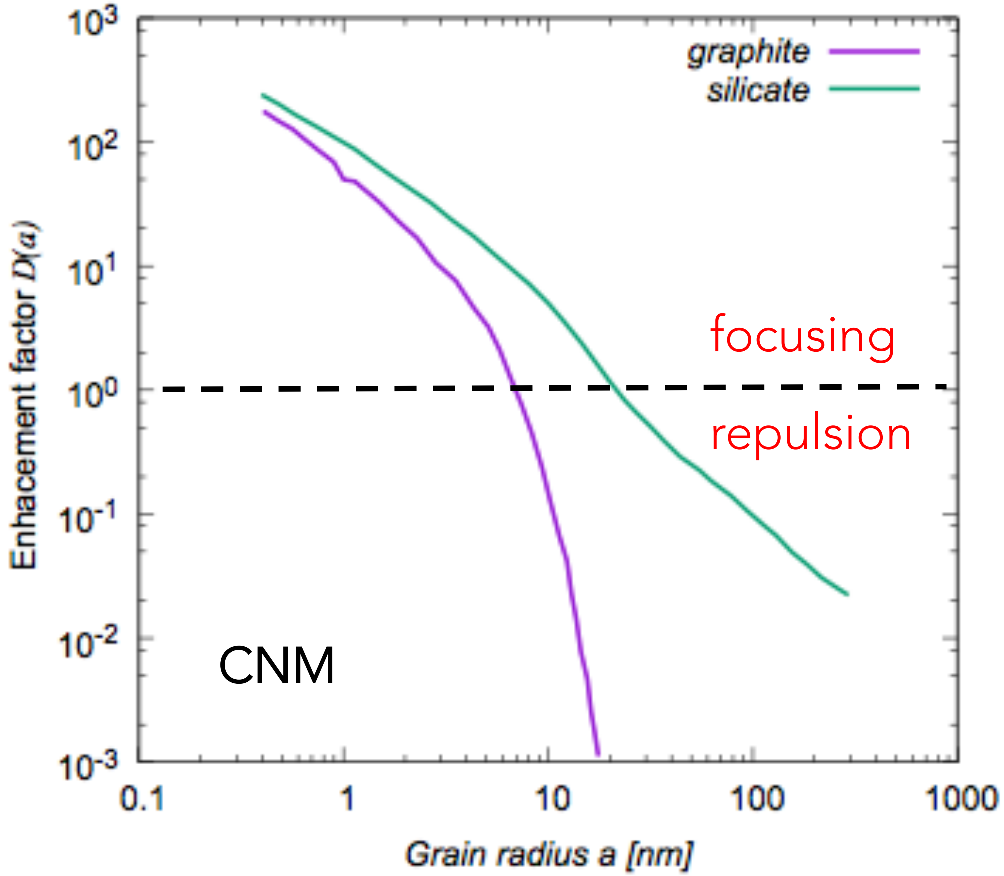
Dust model – growth in ISM

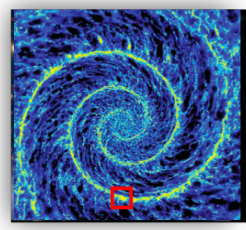


Electrostatic focusing

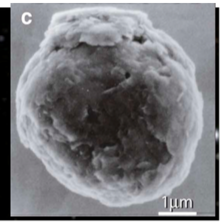
- Grains and gas are charged in diffuse medium
- Changes of the cross section for collision rate
- decreases due to collisions with charges!

a_{min} (nm)	$\langle a \rangle_3$ (nm) CNM	$\langle a \rangle_3$ (nm) other phases
1	0.8	15.8
3	7.7	27.4
5	48.2	35.4





Dust model – growth in ISM

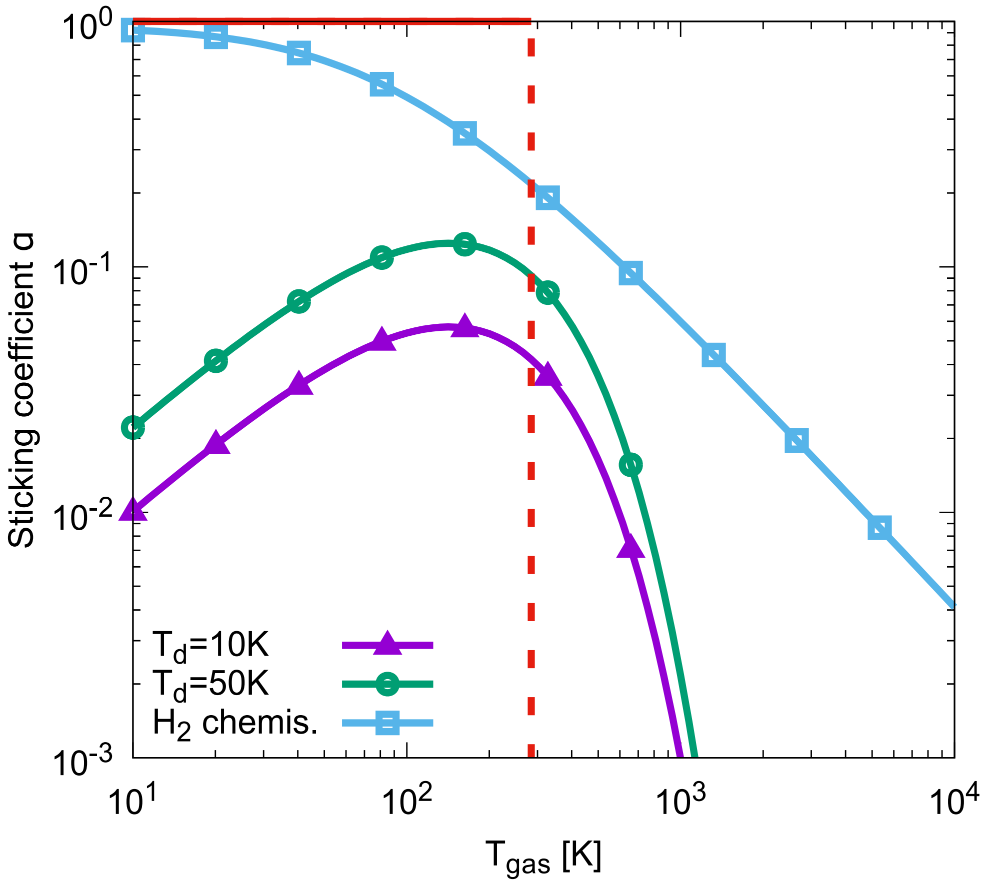


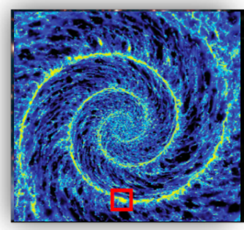
Sticking coefficient

- All dust models assume maximum sticking coefficient ~1
- Problem - overestimate dust growth in warm medium!
- BUT very difficult to measure α

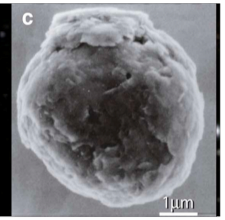
Test 3 cases for α:

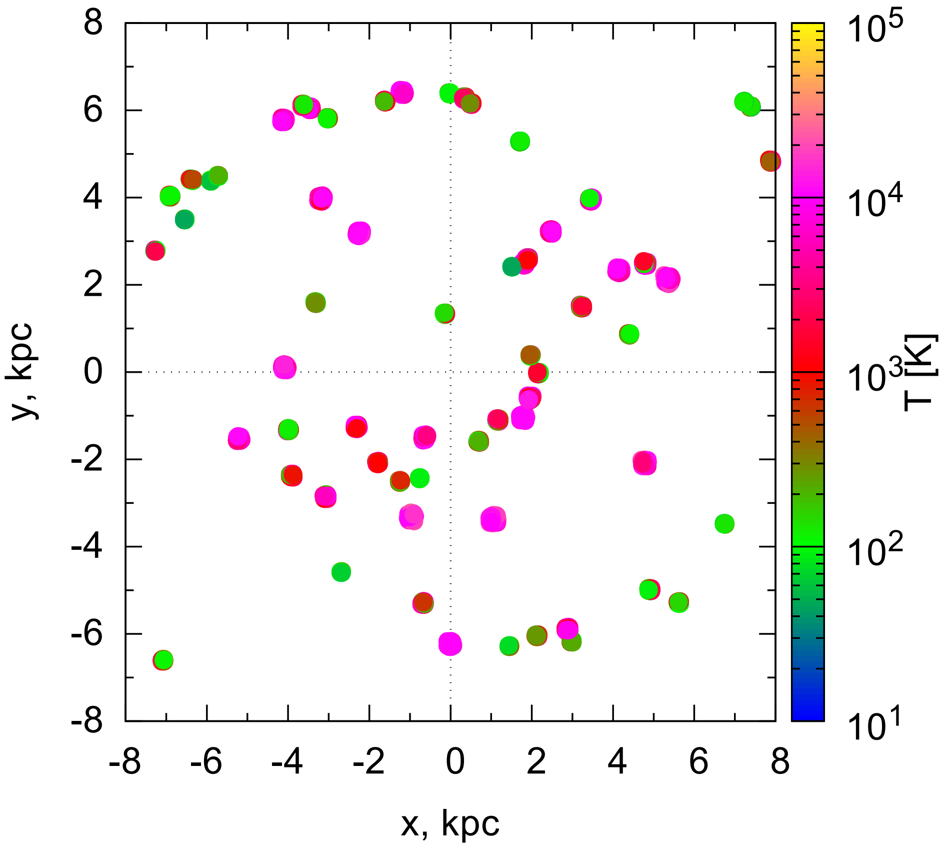
1. Physisorption
2. Chemisorption
3. Growth at CNM with T_{gas}<300K





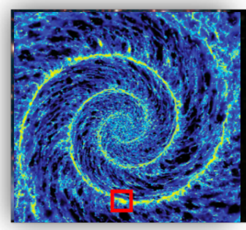
Dust model – destruction



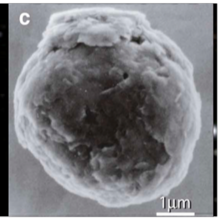


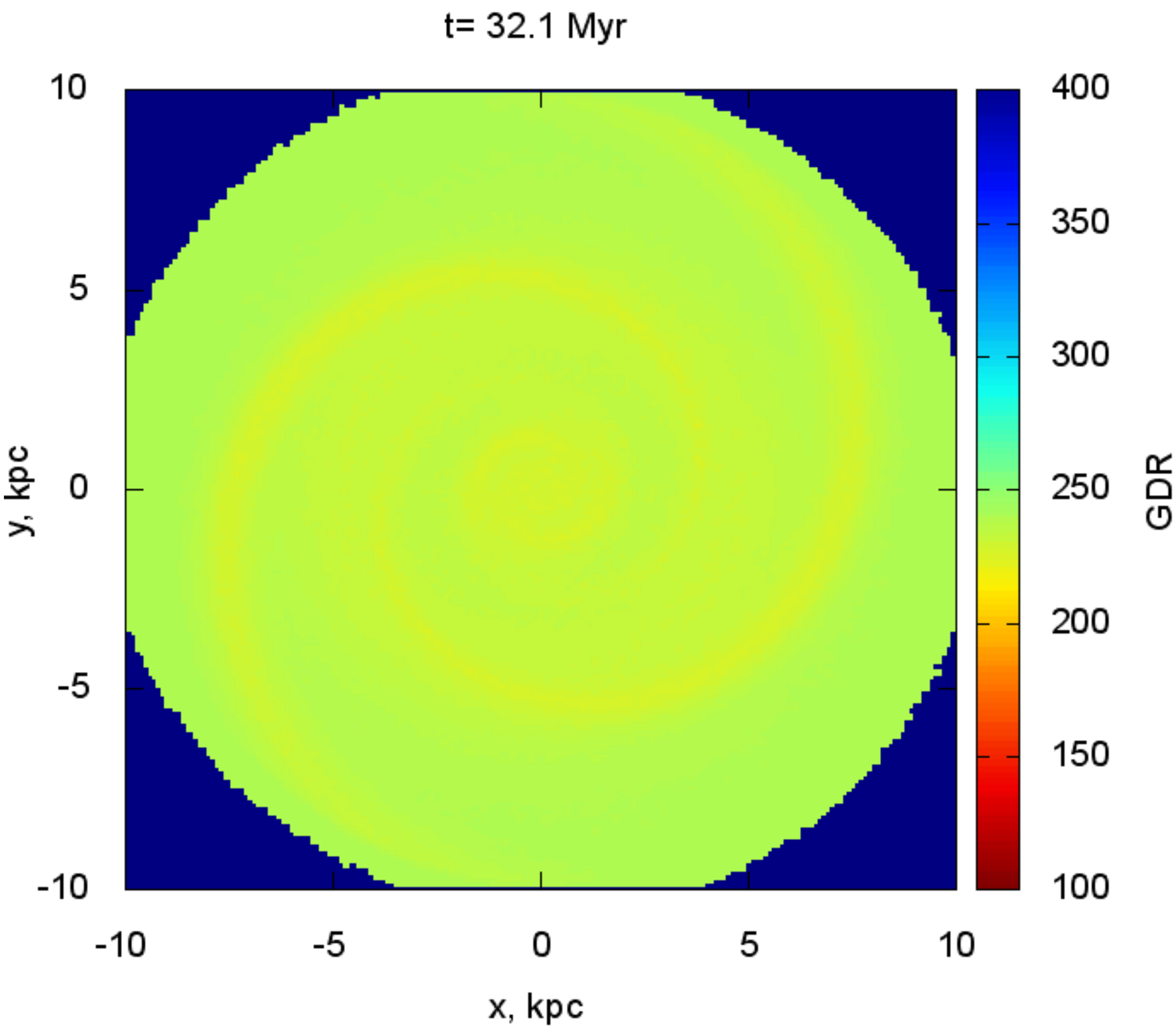
Spatial distribution of SN remnants in a simulation snapshot

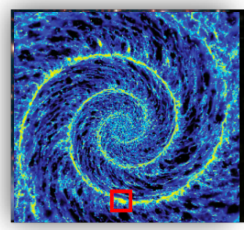
McKee 1989, Tielens+1994, Jones +1994, 1996, Bocchio+2014, Slavin+2015



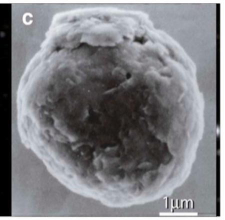
Gas-to-dust ratio map



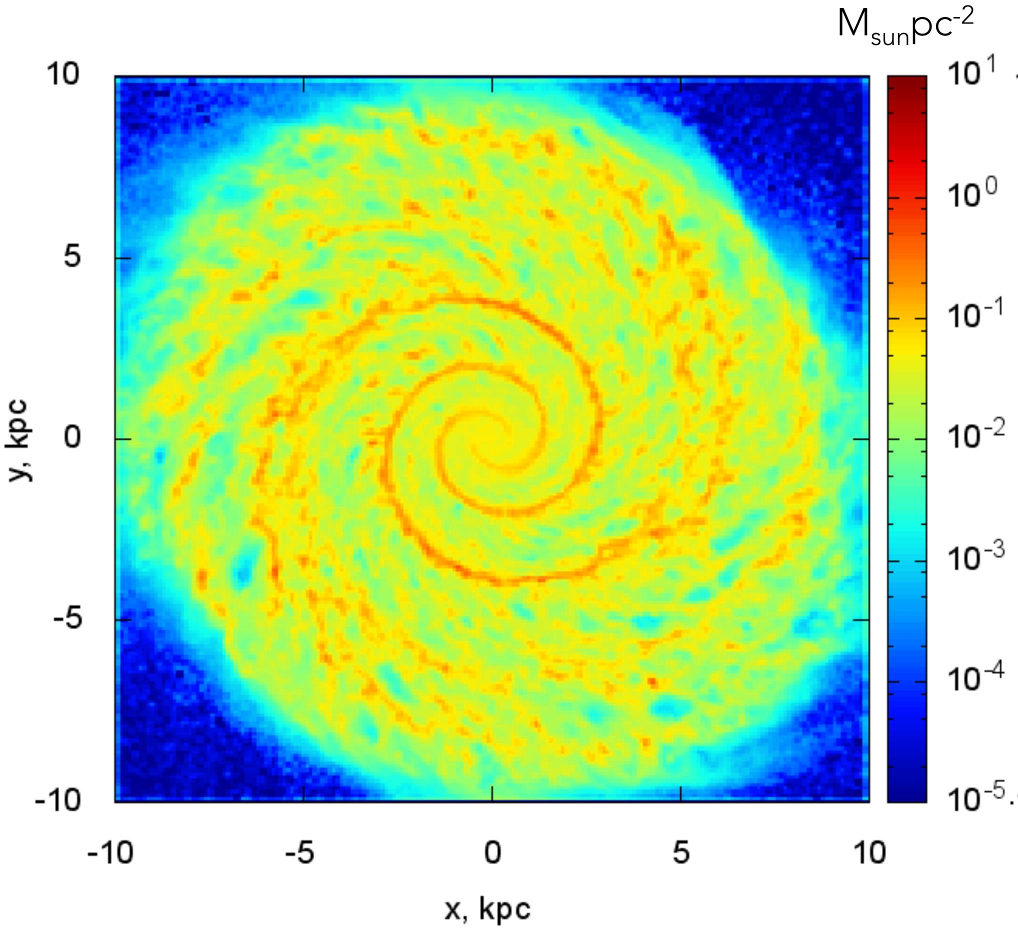




Final dust distribution



Dust surface density map



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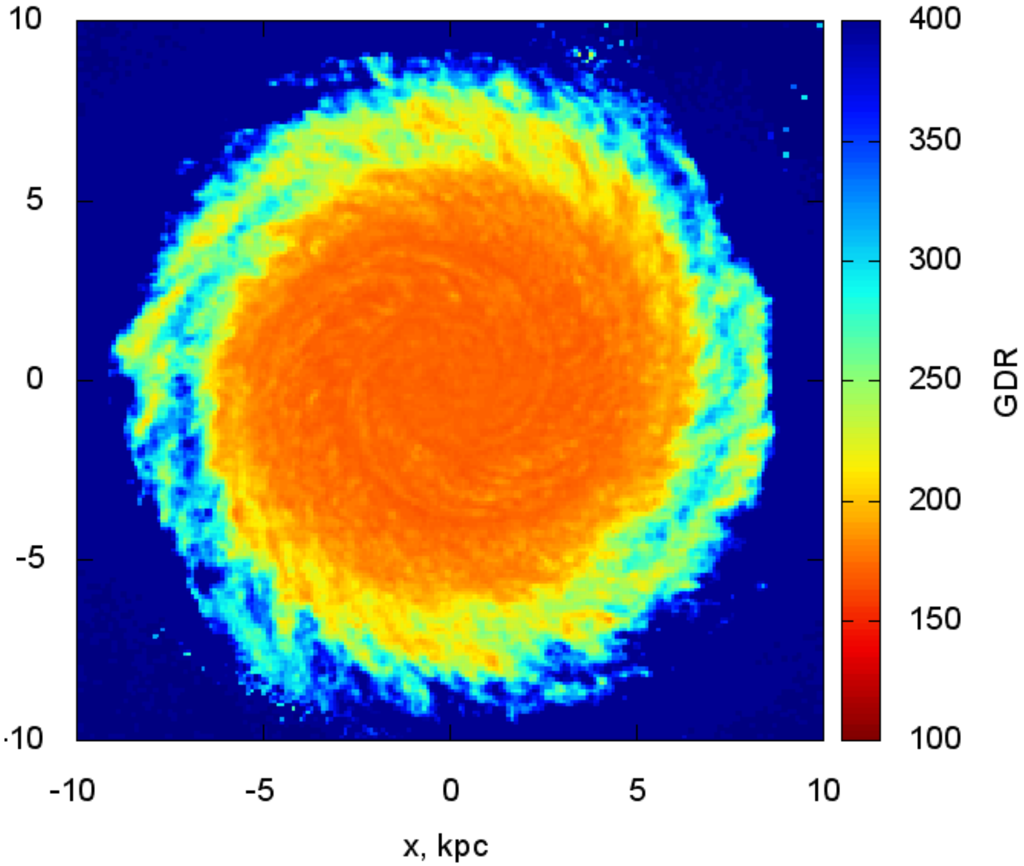
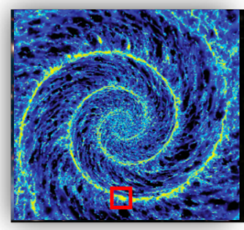
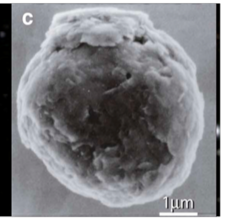
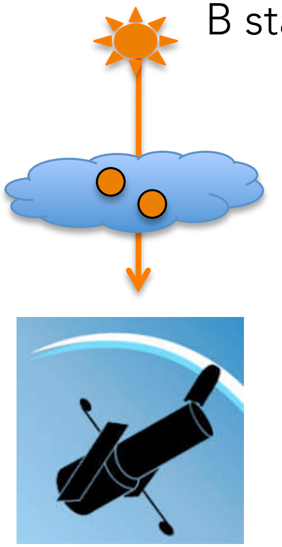


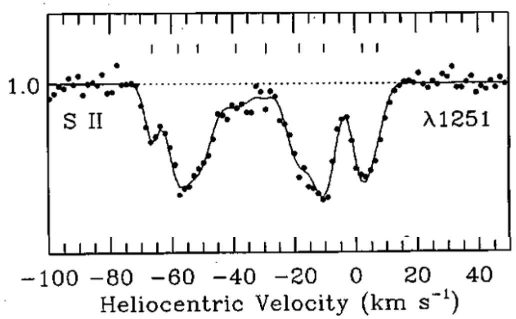


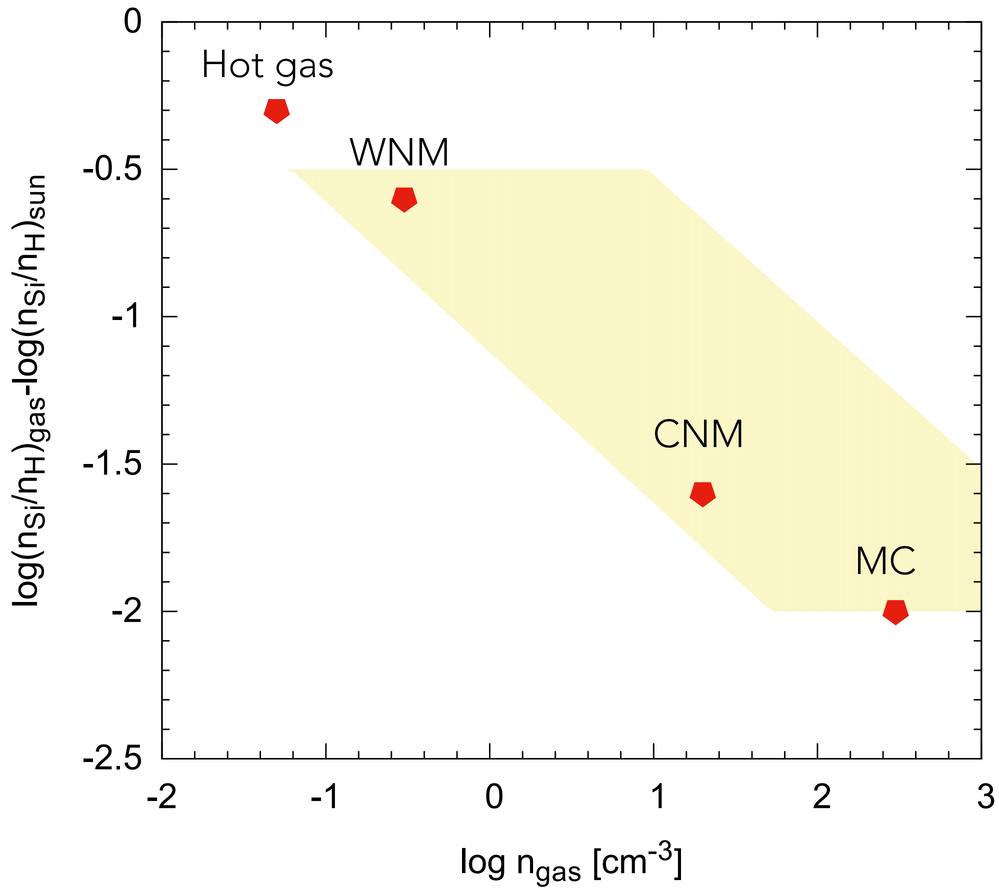
Validation of the models

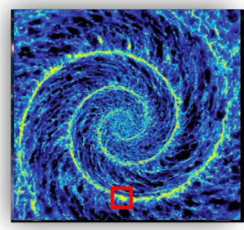


- Si gas-phase abundances from UV absorption lines









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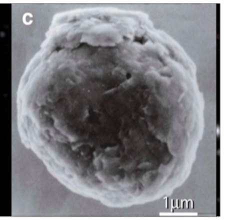
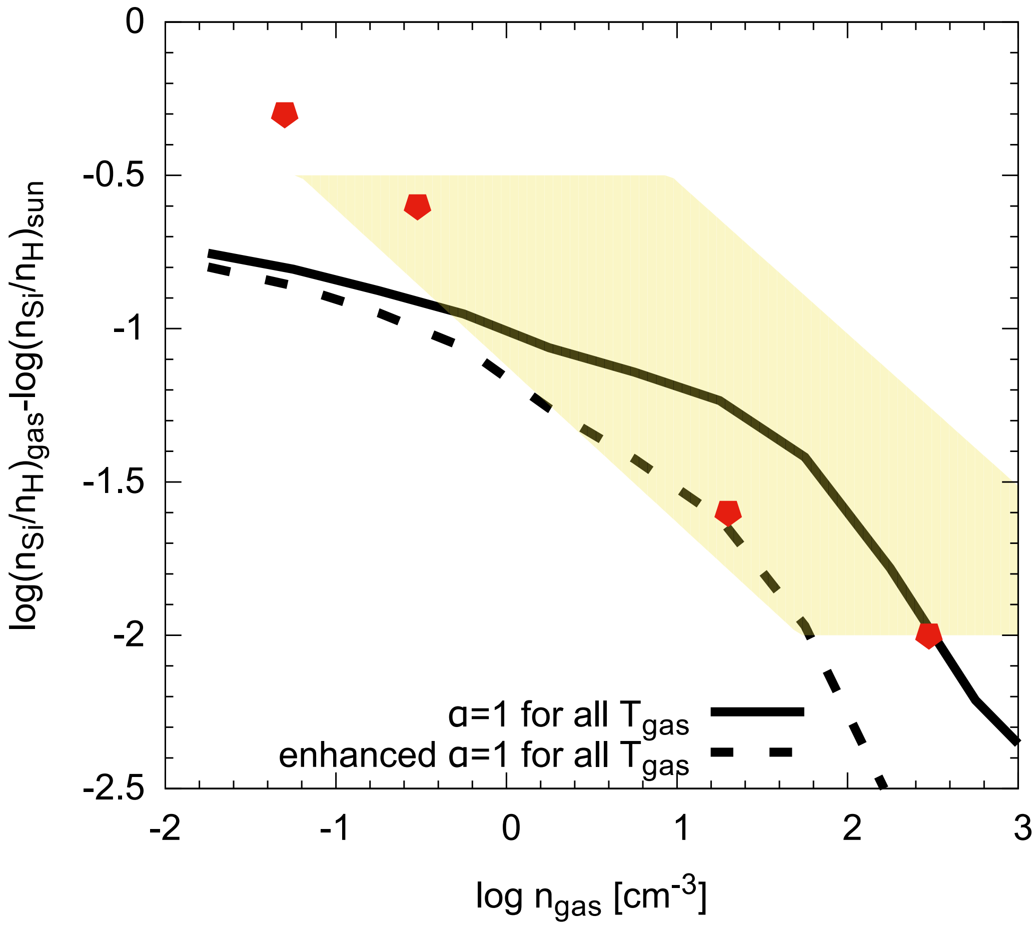
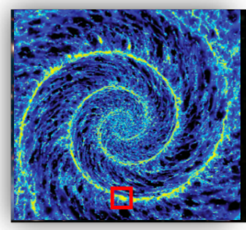


- Si gas-phase abundances from UV absorption lines
- Calculate PDFs for gas phase Si abundances → synthetic relation

Sticking coefficient =1 for all T_{gas} overestimates dust abundances!



Model relations for various sticking coefficient



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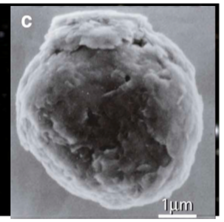
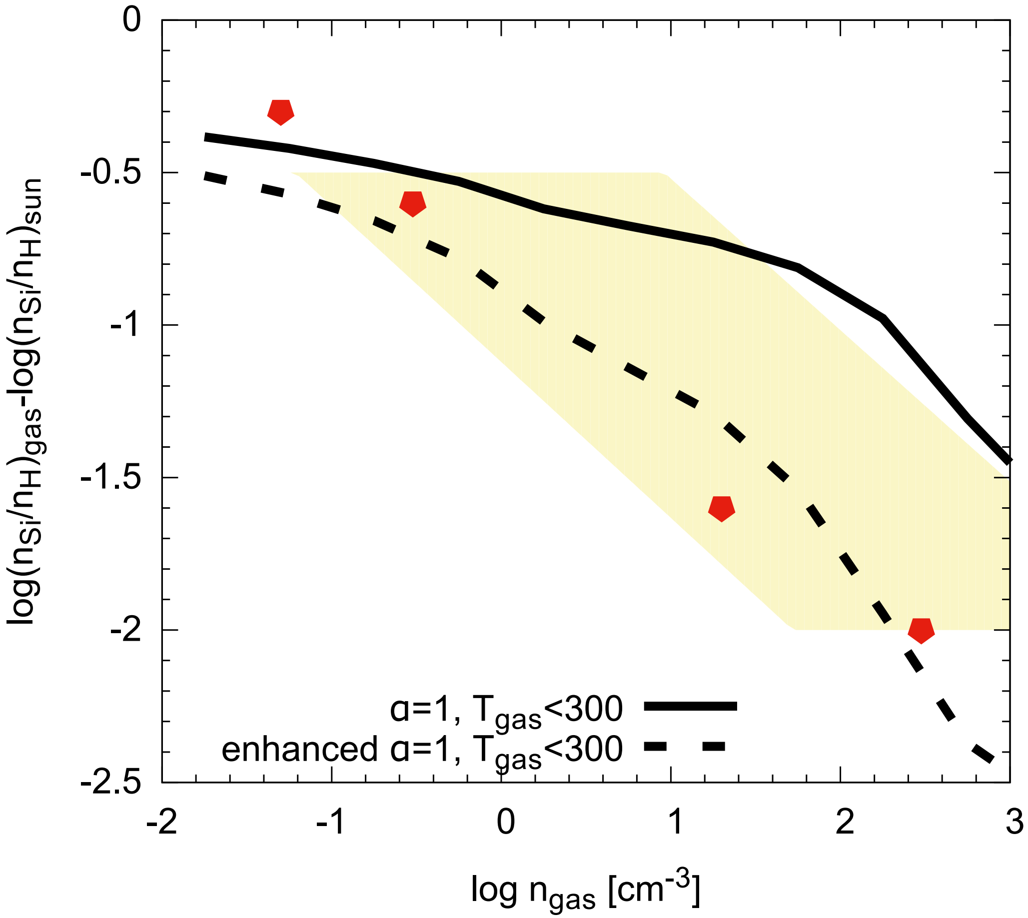


- Si gas-phase abundances from UV absorption lines
- Calculate PDFs for gas phase Si abundances → synthetic relation

Best fit model with sticking coefficient =1 in CNM, 0 for T_{gas}>300K



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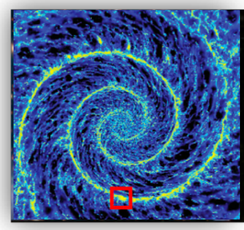
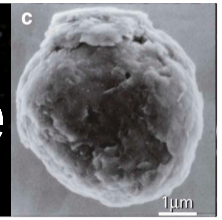
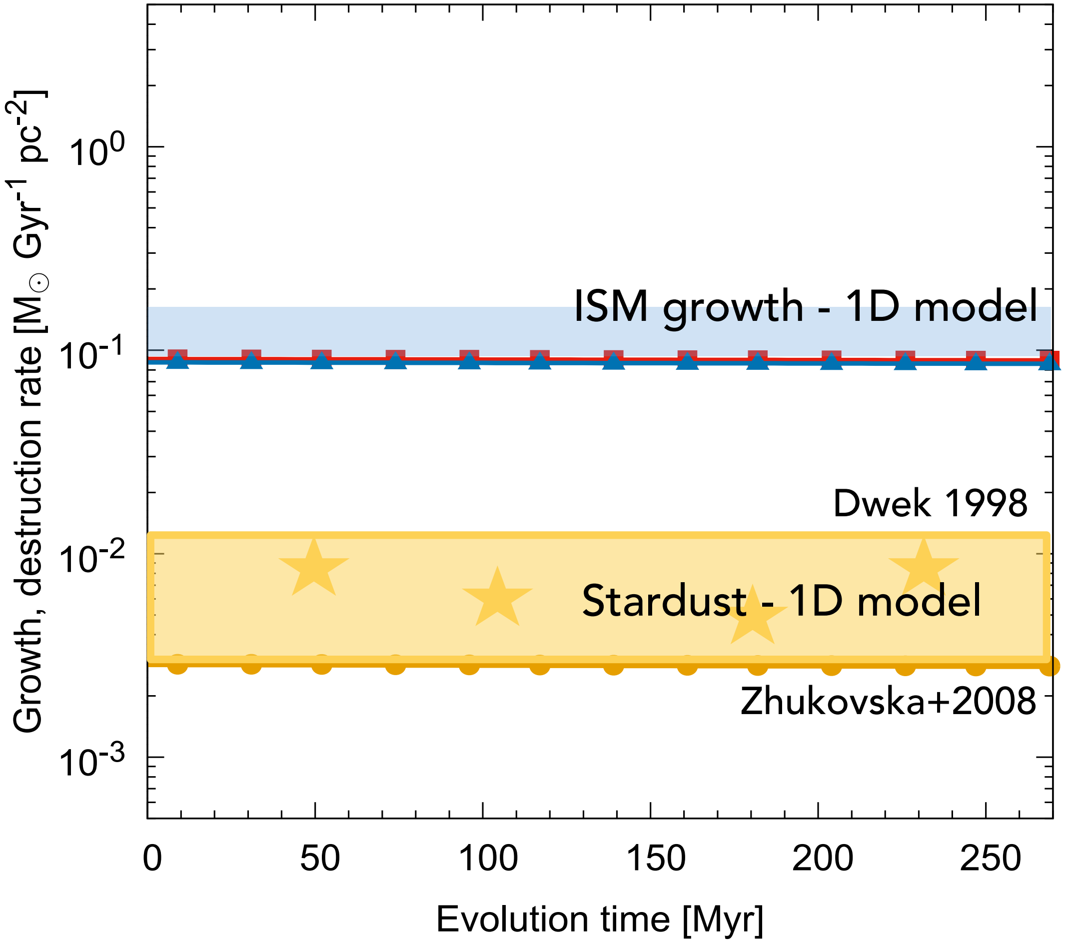


Dust destruction/production balance

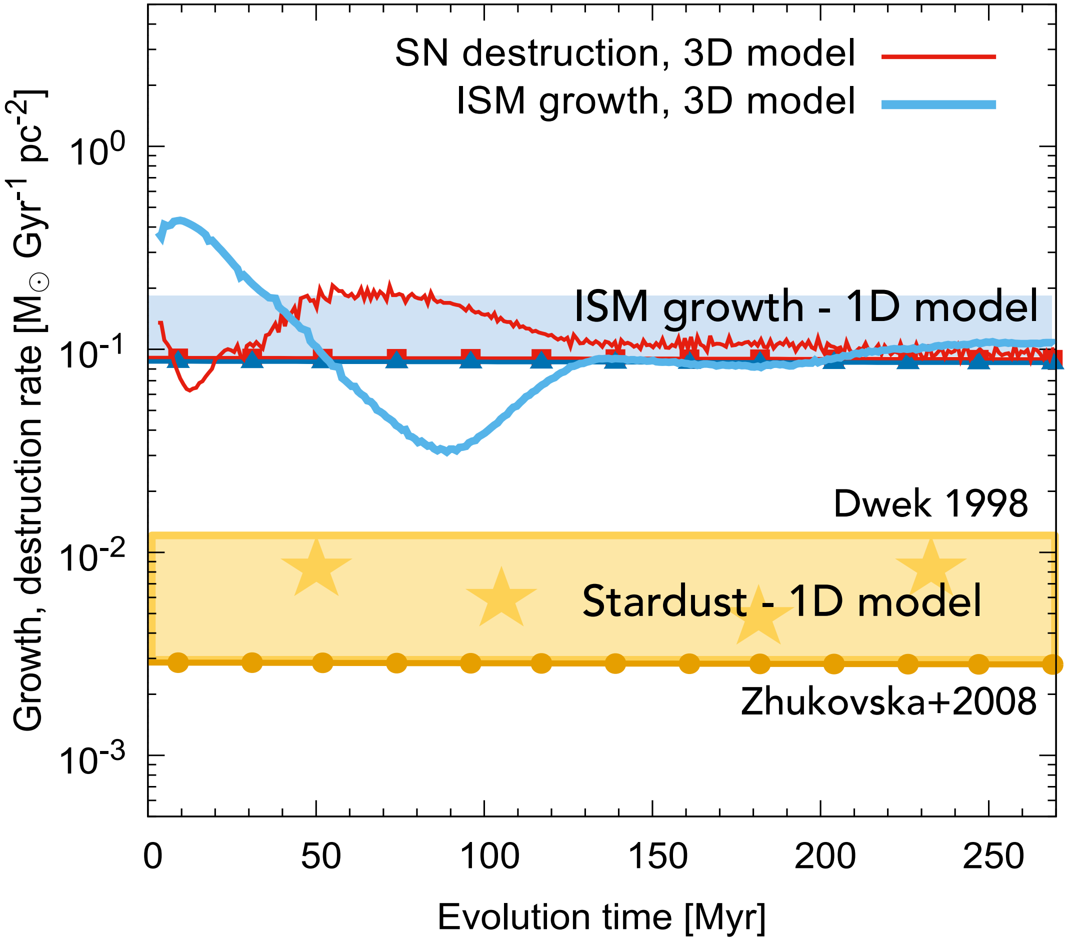


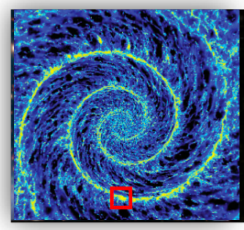
- Comparison with simple one-zone models
- only chemical evolution - fixed physical conditions
- ISM growth dominates dust production



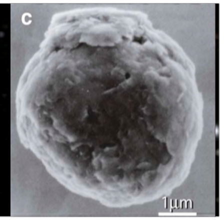
Dust destruction/production balance

- Balance between destruction and production of dust after 130 Myr at the rate $\sim 0.1\ M_{sun}\ Gyr^{-1}\ pc^{-2}$
- ISM growth rate 20-30 times larger than stardust production rate

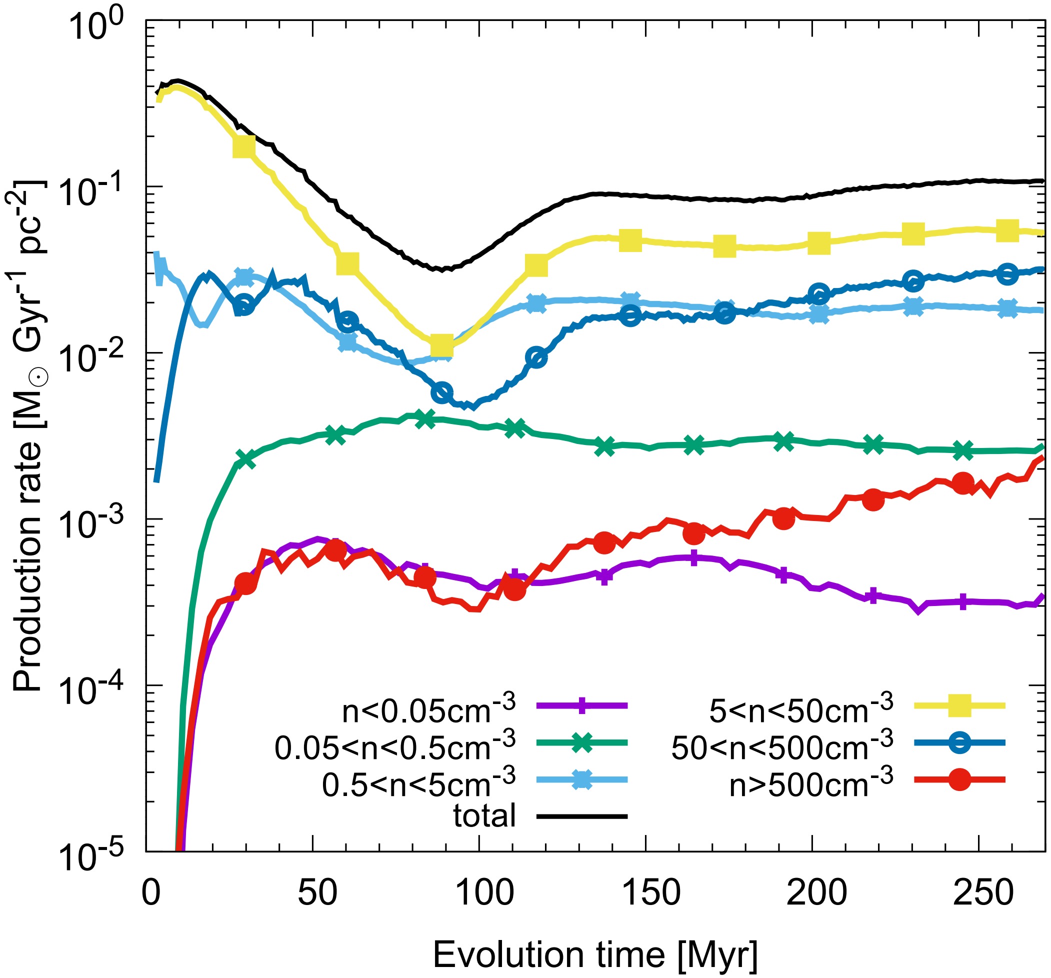


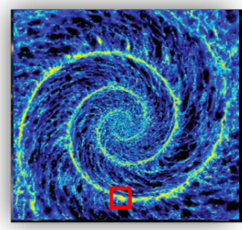


Where does dust grow?

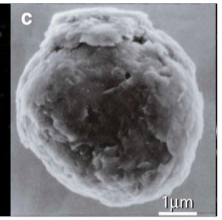


- Highest production rates in CNM at densities $5cm^{-3}<n_{gas}<50cm^{-3}$





Timescale of growth and destruction

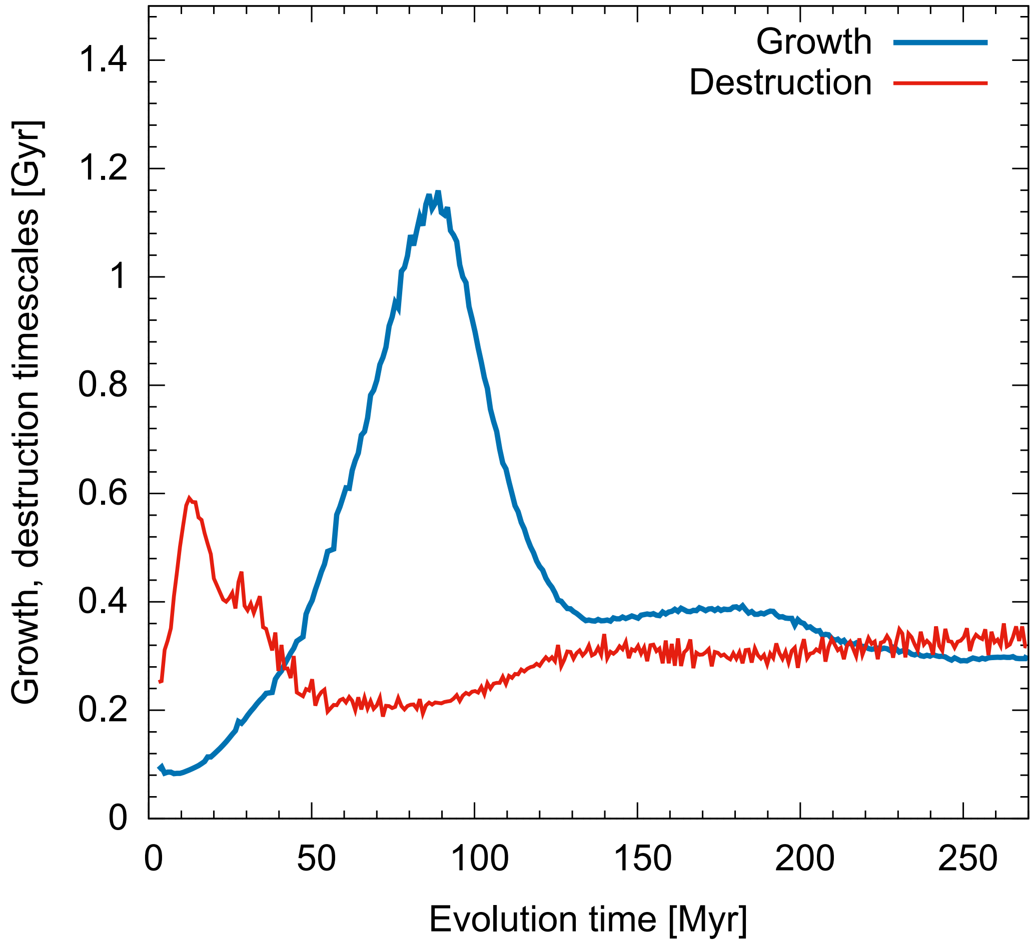


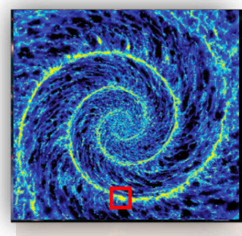
- Timescale at the steady state 400 Myr - similar to "classical" lifetime of grains τ_d~0.5 Gyr

  Jones+1996, Bocchio+2015

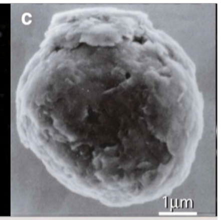
$$\tau_{destr} = \frac{M_{ISM}}{f_{SN} R_{SN} m_{cleared}}$$

- Timescale of dust growth and destruction in the ISM with SPH simulations





Take away messages



- Spatial dust distribution is determined by the balance between destruction and re-formation in ISM. Timescales of these processes ~0.5Gyr << timescale of dust production by stars
- Destruction in the diffuse phase is necessary to explain low Si depletions in diffuse ISM
- Slope of the observed *Si depletion – density relation* is explained by accretion of gas-phase species, its absolute magnitude excludes small silicate grains with radii <3nm
- Sticking coefficient must decrease with temperature in hydrodynamic simulations